LINK BUDGET ANALYSIS FOR DIGITAL SATELLITE COMMUNICATION SYSTEM

A thesis submitted
in Partial Fulfillment of the Requirements
for the degree of

MASTER OF TECHNOLOGY

by

LT. A. BHARGAVA

to the

DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

January, 2000

It

Di

98

sul

R

(P.I
Pro
Dep
I.I.T

2

CERTIFICATE

It is certified that the work contained in the thesis titled "**Link Budget Analysis for Digital Satellite Communication System**," by Lieutenant Amit Bhargava, Roll No. 9810401 has been carried out under our joint supervision and this work has not been submitted elsewhere for a degree.

(P.K. Chatterjee)
Professor
Department of Electrical Engineering
I.I.T. Kanpur - 208016

27 Jan 2000

(K.R. Srivathsan)
Professor
Department of Electrical Engineering
I.I.T. Kanpur - 208016

27 Jan 2000

ACKNOWLEDGEMENT

I take this opportunity to express my sincere gratitude towards Prof. P.K. Chatterjee and Prof. K R. Srivathsan, my thesis supervisors for their invaluable guidance and encouragement throughout the thesis work. They have always been very patient and kind enough to devote their time for discussions and clearing my doubts.

I would also like to thank Mr. CD Banerjee, Mr. Venkateshwarulu, Mr. Saji Kumar and Mr. George Kuruvilla of Doordarshan, India for providing me with valuable information regarding digital transmission through satellites.

I would like to thank my friends Lt. N Nangia, Major JS Sidana, Amit Sharma, RA Warsi and Sahu for providing me with excellent companionship during the entire M Tech program and making my stay memorable at IIT/Kanpur. I thank Vineet, Geeta and Vivek for their kind help in the lab.

I would also like to thank my wife, Pallavi, for her constant support, encouragement and for always standing on my side to give me strength in all my endeavors.

Date : 27 Jan 2000 (Lt. Amit Bhargava)

Place: Kanpur

ABSTRACT

Satellite communication applications extend to various human activities including data communications, TV broadcasting, information distribution, maritime communication and remote monitoring. Satellite communication has gained popularity owing to its broadcast feature and provision of two-way links using standard Earth stations and VSATs. As compared to terrestrial communication links the satellite provides a wide area of coverage (across countries or continents) and higher bandwidth. In satellite communication the system performance is highly constrained by limited power and bandwidth availability. Constant endeavor is being made to achieve higher and higher transmission rates with the given power and bandwidth.

Link budget calculations have been done as part of the hybrid network project undertaken by Electrical Engineering Department, IIT Kanpur. In hybrid networks the forward and return access paths to internet are split, with high speed link, provided in the reverse direction to significantly improve the overall downloading rate. Typically a Digital Satellite communication link can be used as the high speed link. The thesis aims at Link Budget calculations for Digital satellite systems using INSAT series and leased (2DT & PAS-4) satellites by Doordarshan, India. Typical Link budget calculations have been carried out by considering IIT Kanpur as the standard uplink station and a VSAT as the downlink user spread across the Indian mainland.

Contents

2. Satellite Channel Characteristics/Specifications

3. Link Budget Considerations

List of Figures

List of Tables

CHAPTER 1

Introduction

1.0 INTRODUCTION

A communication satellite operates as a distant line-of-sight repeater providing communication services among multiple earth stations in various geographical locations. A basic satellite communication link diagram is shown in Fig 1.1. below :

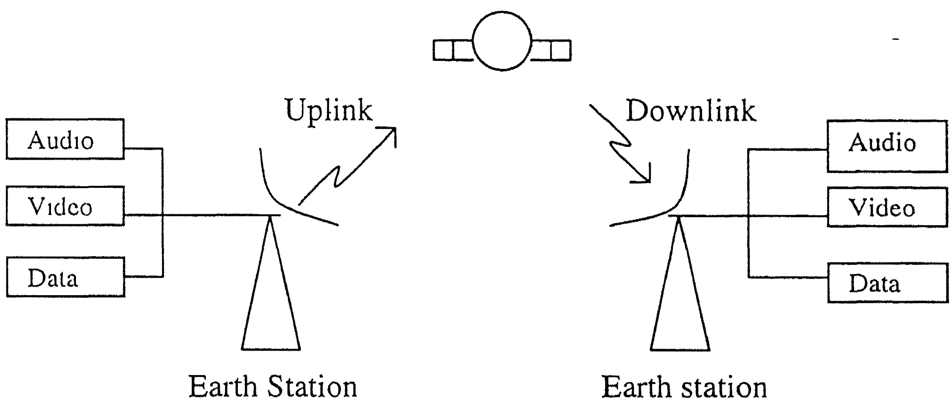


Fig 1.1 A basic satellite communication link diagram.

A complete satellite link consists of three stages – the uplink, the downlink, and the transponder. The uplink represents the link from the transmitting earth station to the satellite. The transponder provides filtering, amplification, processing and frequency translation to the downlink frequency band for retransmission. The downlink represents the part of link between the satellite and the receiving earth station. The most important parameter used to evaluate the uplink & downlink is carrier-to-noise ratio (C/N). It depends on the transmitted power, gain of the transmitting antenna, gain of the receiving antenna and the system noise temperature of the receiving system. Several impairments, primarily intermodulation effects caused by non-linear operation of the satellite amplifier may also be present. Interference from other satellites and terrestrial systems are also collectively characterized by a carrier-to-interference ratio. Satellite

communication has gained tremendous popularity over terrestrial communication due to its wide area of coverage and large available bandwidth feature

1.1 APPLICATIONS OF SATELLITE COMMUNICATION

Satellite communication applications extend to various human activities including information distribution, maritime communication, remote monitoring and more importantly data communications and TV broadcasting.

1.1.1 DATA COMMUNICATIONS

A wide variety of data communication needs are met through satellite owing to its wide area of coverage and large available bandwidth feature. Connection of computer networks through very small aperture terminals (VSATs) has also gained popularity recently. High bit rate transmission makes multimedia applications over satellite also possible.

1.1.2 TELEVISION BROADCASTING

Concept of Direct-to-Home broadcasting is also being visualized in India which is already in use in many countries. In India, the conventional analog television broadcasting is being slowly replaced by more efficient digital broadcasting.

1.1.2.1 ADVANTAGES OF DIGITAL OVER ANALOG SATELLITE BROADCASTING

Digital transmission of TV signals via satellites offer advantage over analog transmission of TV signals, partly due to the inherent properties of digital transmission and partly due to the transmission link via satellite. The various advantages are :

1. Reduced transmission bandwidth due to excellent video compression algorithms. This allows more number of channels available per transponder.
2. Reduced satellite power needed to transmit the digital signal for the same video quality.
3. More immune to noise, interference and undergoes lesser distortion.
4. Provides a potential for using a common format for satellite broadcasting, satellite DTH, cable TV and terrestrial broadcasting.
5. Multiplexing and processing of different TV signals is less complex and costly.

1.2 SATELLITE APPLICATIONS ENVISAGED FOR THESIS

The motivation for the thesis arose from the envisaged use of satellite communication for hybrid network project [11] and distance education program being undertaken at Electrical Engineering Department, IIT Kanpur. In both applications the uplinking is done using standard earth stations and the downlink end user is a receive-only terminal.

1.2.1 HYBRID NETWORKS

In typical situations, normal telephone lines are used for accessing the Internet service provider (ISP). This provides very limited data transfer rates between the user's machine and the internet. and limits the speed with which a user can download information from the internet. This hurts most in applications such as file-transfers (FTP) or world-wide-web (WWW) access as there the data transfer is highly asymmetric i.e. much more data is going from the internet/ISP to the user than in the other direction Significant performance improvement in data transfer rates may be obtained if a high bandwidth channel can be made available for carrying data from the internet to the user. The effective download speed may be increased to levels which would be virtually limited only by the speed of the high bandwidth return channel, while still using the low speed telephone channels for carrying data from the user to its ISP.

Using satellite channels for this purpose is an extremely attractive idea as these channels not only provide very high bandwidth but also have a very wide geographical reach. The satellite provides the "high-speed return channel" as long as the user can install receive-only satellite dish to receive data from it. The receive-only satellite dish is small in size, cheap to manufacture, install and maintain. High-speed cost-effective connectivity to the internet is then available to the user by using a modem for uplink traffic to its ISP and a receive-only satellite dish for downlink traffic from a suitable internet application server. The term hybrid refers to the fact that the network uses a mix of satellite and terrestrial communication links.

In a hybrid network the satellite receive dish need not have transmit capability, and therefore, be much less expensive receive-only terminal. An example of a hybrid

network using a combination of terrestrial links through a standard ISP and a broadcast satellite link is shown in Fig. 1.2.

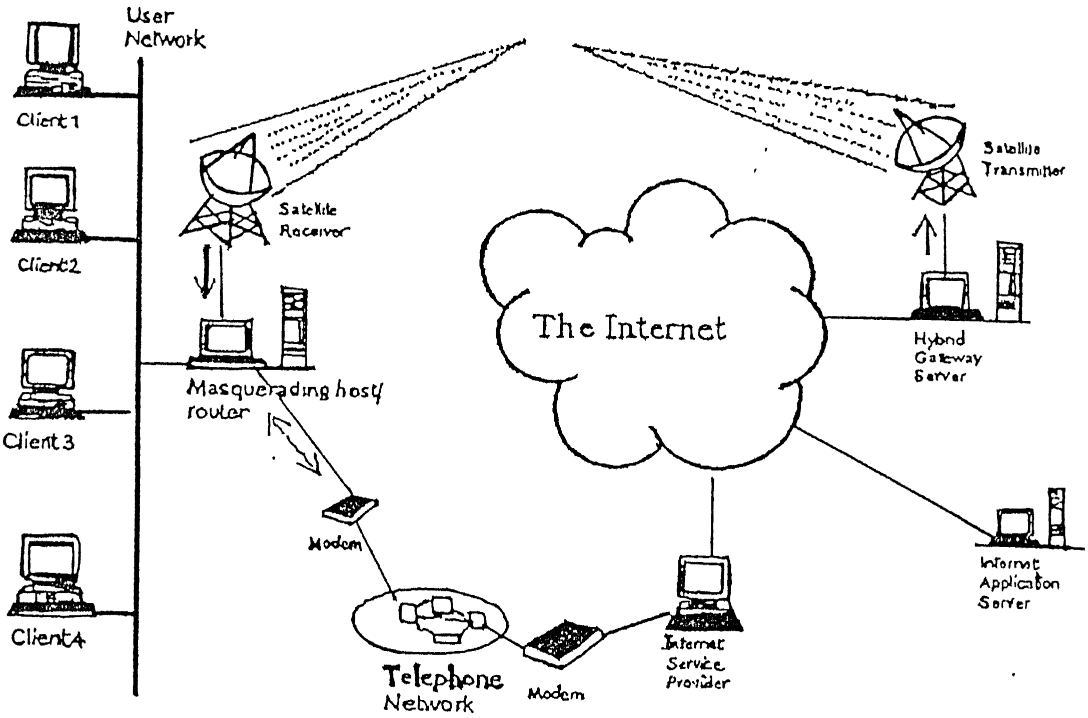


Fig 1.2 A hybrid network

The downlink through the satellite channel has a very high bit rate i.e. typically of the order of several megabits per seconds. The hybrid gateway server gets data from the internet application server and sends the data to the satellite transmitter. The traffic from the user network to the internet goes via telephone links and the return traffic comes via the receive-only dish.

1.3 ACCESS MODES

Multiple access permits more than one earth station pair to utilize transponder simultaneously The first technique is the frequency division multiple access (FDMA)

which employs multiple carrier within the same transponder. Each uplink radio frequency (RF) carrier occupies a defined frequency slot and is assigned a specific bandwidth. The second technique is the time division multiple access (TDMA) in which a single carrier is time-shared among many users. It operates in burst mode such that the transmission bursts form all stations arrive at the satellite transponder consecutively and are contiguously interleaved without overlapping in time. It allows the transponder amplifier to operate in saturation and thus deliver large Effective Isotropic Radiated Power (EIRP). The third multiple access technique is the code division multiple access (CDMA) in which all uplink signals occupy the same frequency band at the same time. Each has its own pseudorandom code, which is chosen form an orthogonal set, which is used to separate the desired signal from the other signals.

1.4 DIGITAL SATELLITE COMMUNICATION SYSTEM

The schematic block diagram of a digital satellite communication system is shown in Fig. 1.3 [9]. The source coded Audio, Video and Data signals are channel encoded so that the transmission channel is rendered virtually transparent.

The channel encoding is also called as forward error correction(FEC) which comprises three stages – outer coding, interleaving and inner coding. The predominant impairment in the satellite communication channel is noise, which leads to randomly, distributed single bit error for coherent demodulation methods. In addition to noise there will be occasional interference of various kinds, some of it being impulsive and lead to bursts of errors. The outer code is chosen to have good burst error correcting capabilities. Typically, Reed Solomon (RS) block code is used. For example in MPEG-2 RS (204,188) code is chosen which can correct 8 byte errors in the total 204 bytes of the packet. The interleaver placed between the outer and inner coder has the purpose of breaking down any lengthy bursts or errors reaching the outer decoder in the receiver. Contiguous errors are dispersed thus reducing the burst lengths. Interleaving process does not increase the bit rate. The bit stream at this stage is scrambled to render it as random as possible and is of assistance during symbol clock extraction at the receiver and in maintaining a smooth modulated spectrum. A defined pseudo-random bit stream (PRBS) is added modulo-2 to the packet stream. Inner coding using convolutional codes allows for a flexible code rate in order to choose the most convenient error

correction for each service or bit rate. It is based on the puncturing technique usually included in all Viterbi decoders. The inner code rates can be 1/2, 2/3, 3/4, 5/6 and 7/8. These rates progressively degrade the code in its power to correct errors.

Channel coding is followed by modulation. The most popular modulation schemes for satellite communication are BPSK and QPSK. The complexity of modulation may be increased so that more information per symbol can be transmitted. The problem with more complex and efficient modulation schemes is that a higher C/N is needed at the receiver for demodulation. Due to the constraints of satellite transmitted power and the receiver antenna size, higher values of C/N may not be feasible for some applications. Modulation schemes involving amplitude changes in the carrier are least preferred due to channel non-linearities owing to satellite transponder operating near saturation to get maximum radiated power.

Modulator is followed by an upconverter, which is used to translate the carrier to the uplink frequency, which is typically 6 GHz for C-band and 14 GHz for Ku band. The upconverted signal is then passed through a high power amplifier (HPA) to get the desired radiated power for uplinking.

The satellite transponder translates the received signal to the downlink frequency and then amplifies it before transmitting again. The lower frequency band is used on the downlink to exploit the lower atmospheric losses (path loss) thus minimizing satellite power requirements. Satellite transponder provides a relatively large gain while maintaining relatively low noise operation. Typically, for such operation travelling wave tube (TWT) or solid state power amplifiers (SSPAs) are used.

At the receiver the received downlink signal is amplified in an low noise amplifier (LNA) and down converted to intermediate frequency (IF) and then demodulated. Inner decoder performs first level error protection decoding. It should produce an output BER of $2x10^{-4}$ or lower. This output BER corresponds to a Quasi error free (QEF) service after outer code correction. Inner decoding is followed by de-interleaving. Outer decoding is then done to provide a BER of 10^{-10} or 10^{-11}.

1.5 SATELLITE LINK BUDGET ANALYSIS

The satellite applications are designed and assessed using Link Budget analysis. The aim of Link budget analysis is to account for all the signal power and signal losses

so that a sufficient signal power can be delivered to the receiver to maintain the required C/N. The complete link budget comprises three parts:

- Uplink budget
- Downlink budget
- Overall budget

Thermal noise plays a very significant role in the link budget. The thermal noise level at RF or at IF is referred by the C/N ratio included in the channel bandwidth. Since the same value of C/N may correspond to much different values of carrier power depending upon the channel bandwidth. A more transparent indication of the required carrier level is offered by carrier-to-noise power density ratio called C/N_o where N_o is the noise contained in a unitary bandwidth.

$N_o = kT$

where

k = Boltzmann's constant = -228.6 dBW/K

T = System noise temperature (°K)

In digital transmission systems, link budgets are evaluated using the parameter E_b/N_o It is defined as ratio of energy per transmitted information bit to noise density. It is related to C/N_o by the relation:

$$\frac{E_b}{N_o} = \frac{C}{N_o} - 10\log_{10}(R) \qquad \text{where}$$

R = bit transmission rate

1.5.1 UPLINK BUDGET

The uplink C/N_o is given by: -

$$\left.\frac{C}{N_o}\right)_{up} = \mathrm{EIRP} - L_s + \left(\frac{G}{T}\right)_{sat} - k$$

where

L_s = system losses + path loss

The uplink budget mainly depends on the EIRP of the transmitting earth station and the G/T of the satellite transponder. G/T, which is the ratio of total gain provided to the received signal and the receiver system noise temperature is specified by the manufacturer. However, the uplink C/N_0 can be increased or decreased by changing the uplink transmitted power. Another important parameter used in uplink calculations is the satellite transponder saturation flux density (SFD). It is the required flux density of single carrier at satellite transponder to drive its HPA to saturation to give maximum output power. To work in the linear region of the high power amplifier (HPA) the total carrier flux density at the transponder must not exceed SFD. The difference between the actual total flux density at the transponder and SFD gives input backoff which is a very important factor indicating the level of intermodulation products for multiple carriers. The levels of intermodulation products fall off very steeply with increase in input backoff.

1.5.2 DOWNLINK BUDGET

The downlink budget is given by:

$$\left.\frac{C}{N_o}\right)_d = \mathrm{EIRP} - L_s + \left(\frac{G}{K}\right)_{ES} - k$$

where

L_s = system losses + path loss

The downlink budget depends on the satellite EIRP and the receiver system G/T. The satellite EIRP is varied by changing the input backoff. The satellite EIRP reduces from its maximum value with increasing input backofff. The G/T of the earth station depends on the receiving antenna size (its gain) and the total system noise temperature. In some applications the receiver G/T also incorporates the losses between the antenna and the LNA. Typically, the dish antenna size can be increased to increase G/T.

1.5.3 INTERMODULATION

The carrier-to-intermodulation noise is denoted by $(C/N)_i$. It is a function of the number of carriers, their modulation characteristics and the amplitude and phase characteristics of the transponder HPA. The satellite HPAs saturate and are non-linear when operated near their rated outputs. The SSPAs used onboard satellites tend to remain more linear as they approach saturation than TWTAs. The amplifier also have overall phase shifts that are a function of signal level-giving rise to AM-to-PM conversion and further generation of spurious frequencies. These spurious frequencies which are generated due to intermodulation and AM-to-PM conversion are grouped in a composite value of $(C/N)_i$ and are measured or calculated and sometimes specified by the manufacturer. The $(C/N)_i$ increases with increasing input backoff.

1.5.4 INTERFERENCE

Interference coming from sources such as cross polarized transponder, adjacent satellites and various terrestrial systems falling within the required band of interest are grouped together and are referred by carrier-to-interference ration C/I.

1.5.5 OVERALL LINK BUDGET

The overall system C/N_0 is given by the relation: -

$$\left(\frac{C}{N_0}\right)_{sys}^{-1} = \left(\frac{C}{N_0}\right)_{up}^{-1} + \left(\frac{C}{N_0}\right)_{d}^{-1} + \left(\frac{C}{N_0}\right)_{i}^{-1} + \left(\frac{C}{N_0}\right)_{I}^{-1}$$

Each of the four ratios on the RHS has to be first calculated individually and then the overall system C/N_0 is found out. E_b/N_0 is then calculated and examined as to whether it meets the system requirements.

1.6 AIM OF THESIS

The Link Budget calculations are required for Digital satellite systems using INSAT series (2C and 2E) and leased (2DT and PAS-4) satellites by Doordarshan, India. In the uplink case IIT Kanpur has been considered as the standard earth station

with antenna size 6.3 m. In the downlink case a VSAT as a user spread across the Indian mainland is considered. The uplink and downlink frequencies have been taken as 6 GHz and 4 GHz respectively to commiserate with the C-band available with Doordarshan for television broadcasting. Calculations are done for digital information bit rates varying from 1 to 5 Mbps.

Satellite parameters such as maximum EIRP of each platform, I/O backoff relationship, intermodulation distortion, satellite G/T, satellite SFD, satellite locations and their semi major axis etc. provided by Doordarshan, India have been used in the calculations.

Link Budget analysis have been done for the following cases:

- Simulcasting with Doordarshan, India for satellites 2DT and 2E with limited bandwidth available for transmission. A typical end user situated at Mumbai, Bangalore, Srinagar and Guwahati is considered.
- Full transponder is available and multiple carriers are used to broadcast more number of channels simultaneously.
- TDMA mode of operation so that higher EIRP can be extracted from the satellite transponder.

1.7 LAYOUT OF THE THESIS

Chapter 2 contains the satellite channel performance specifications which define the signal characteristics and impairment as it passes through it. Chapter 3 deals with the various design parameters and system losses that govern a link budget. Chapter 4 contains Link budget calculations carried out for different access modes. Chapter 5 contains the general conclusion and the scope of future work.

A list of references is placed at the end.

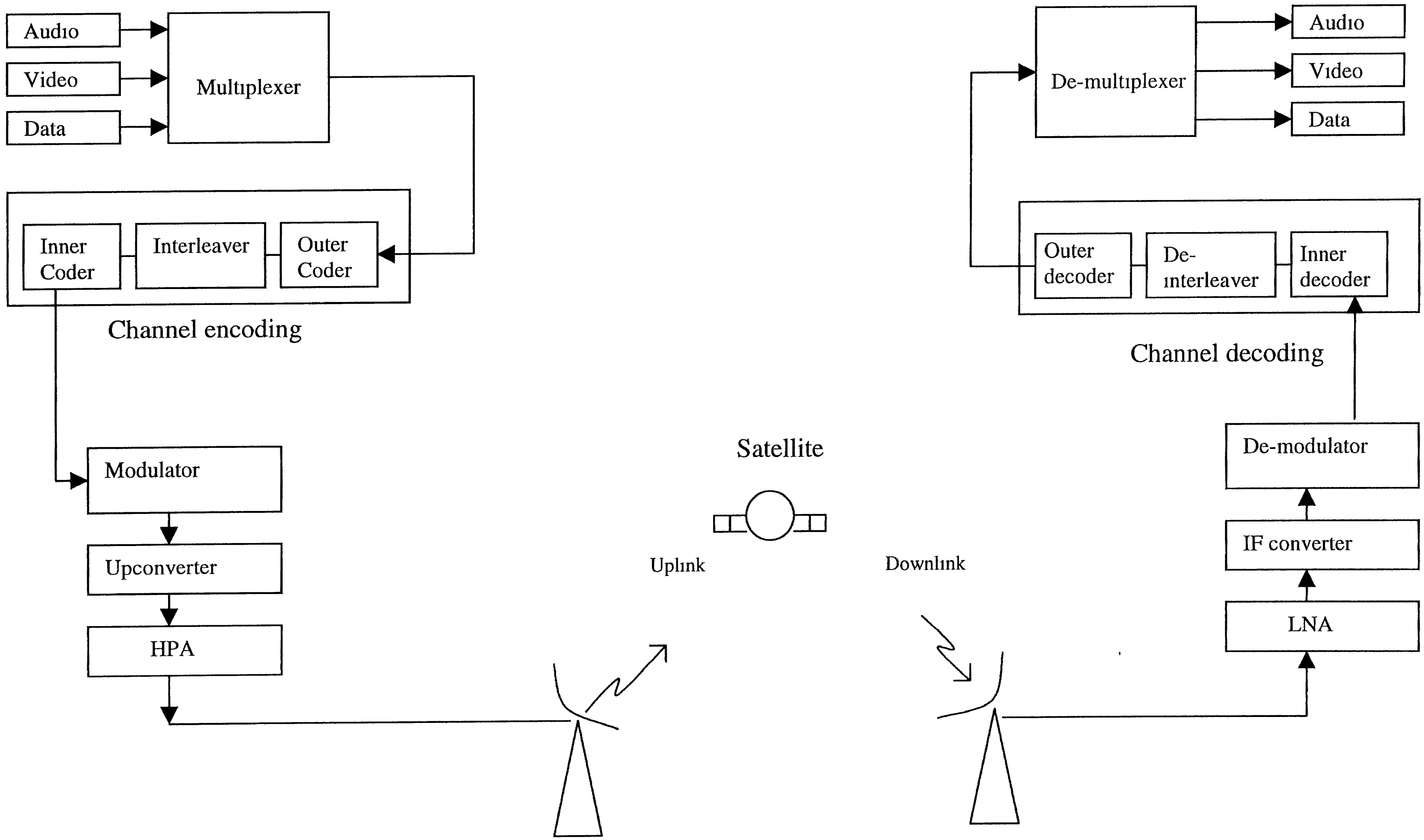


Fig 1.3 Digital Satellite Communication Block Diagram

CHAPTER 2

Satellite Channel Characteristics/Specifications

2.1 INTRODUCTION

Doordarshan has adopted simulcasting for digital broadcasting purposes. It uses INSAT 2C & 2E and leased satellites 2DT & PAS-4 for TV broadcasting. An unused band of 6 MHz is created at the lower or upper end of the transponder by shifting the carrier frequency of the analog signal. This unused band is then used for simulcasting of digital signal as explained below.

2.1.1 SIMULCASTING

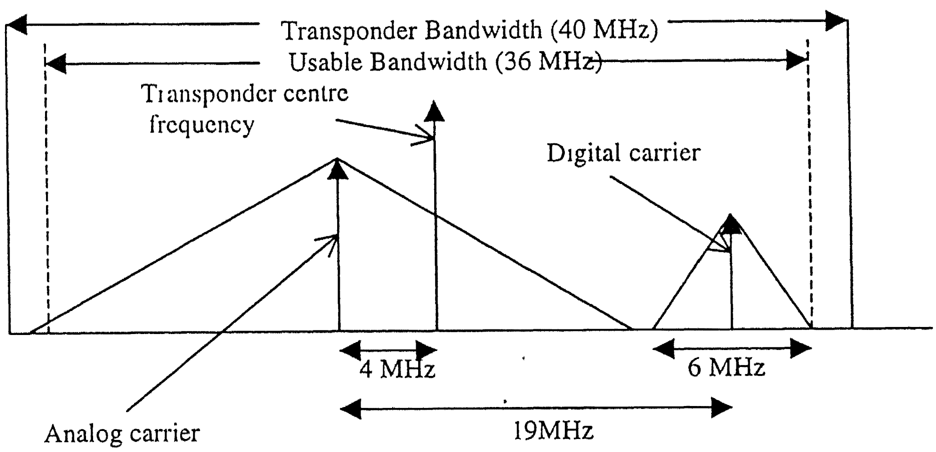


Fig 2.1. Simulcasting as adopted by Doordarshan, India.

The utilization of channel bandwidth of 36 MHz by Doordarshan, India for simulcasting is as shown in the Fig 2.1. The bandwidth occupied by the analog signal is 30 MHz and was usually centered at the centre frequency of the transponder channel. The analog signal used to occupy 30 MHz only and 3 MHz on either side (totally 6

MHz) was wasted. This wastage was done away with by using it for digital broadcasting purposes. To accommodate the digital signal in the same transponder the carrier frequency of the analog transmission is shifted up or down by 4 MHz away from the centre and an unused band of 6 MHz becomes available at the lower or upper end of the transponder channel. The digital signal carrier was kept 19 MHz away from the analog signal carrier. Ideally the frequency separation could have been 18 MHz but was done to avoid spectrum overlap. The digital signal transmission was done to support a symbol rate of 5 Msps with QPSK modulation. This gives a digital carrier noise bandwidth of 6.9 MHz. Since this bandwidth is greater than 6 MHz a difference of 19 MHz in respective carrier frequencies ensured no spectrum overlap.

Doordarshan has presently started broadcasting of its few services in both analog and digital mode simultaneously using the same transponder. For example, DD-1 national analog and digital service use transponder C10 of INSAT-2E. The downlink frequency of analog service is 3849 MHz and that of digital service is 3830 MHz. Similarly DD-2 metro analog and digital service use transponder C12 of INSAT 2E. The downlink frequency for analog service is 3929 MHz and that of digital service is 3910 MHz. This transmission of same service in both analog and digital mode simultaneously using the same transponder is called **Simulcasting**.

Doordarshan, India is planning simulcasting of all its regional services in near future. This would enable them to switch over to Digital Video transmission smoothly. Presently, it is unable to switch only to Digital broadcasting because a large number of earth stations across India are equipped to receive satellite signals only in analog mode.

In simulcasting, the digital signal EIRP was allotted between 18 to 22 dBW depending upon the total satellite EIRP. Major portion of power was given to the analog signal to keep the video quality high over the entire area of coverage since priority is still given to the analog transmission. This power sharing imposes severe restrictions on the digital signal which becomes both severely power as well as bandwidth limited.

In the case of Doordarshan, the digital signal was received using standard TVRO dish antenna of size approximately 6.3 to 7.2m. This gave the receiver system a G/T of nearly 25 dB/K in C-band. The overall E_b/N_0 obtained is in the range of 8 – 10 dB, which is sufficient for good quality video transmission. Digital data transmission of

10 Mbps with QPSK modulation was achieved. The power limitations of the digital signal were compensated by large receiving antenna.

The intermodulation distortion was negligible since only two carriers operated per transponder and marginal input backoff was also given. The carrier-to-interference ratio C/I, was taken to be 20 dB.

2.2 SATELLITE CHANNEL CHARACTERISTICS

Satellite channel characteristics play a very major role in overall system design. It mainly comprises the input and output filters, input and output multiplexers, and mainly the high power amplifier (TWTA or SSPA). The high power amplifiers normally operate in saturation or near saturation and make the channel non-linear. The signal on passing through such a channel undergoes various non-linear distortions, which have to be taken into consideration while accounting the overall link performance. A few satellite channel characteristics that are of paramount importance are given below and have been quoted from INSAT 2C/2D documents [12]. Typical INSAT 2C specifications are given in Table 2.1.

2.2.1 PAYLOAD PERFORMANCE CHARACTERISTICS FIXED SATELLITE SERVICE (FSS) C-BAND

The C-band FSS payload operates in the 6 GHz uplink and 4 GHz downlink bands and provide 18 channels for communication. Out of this 12 channels are in the normal C-band and remaining 6 in the extended C-band.

A block diagram of the payload is shown in Fig. 2.2. Signals received by the 70-cm prime focus fed antenna and through pre-select filters in the normal and extended C-bands are fed to the corresponding receivers. These receivers have a two stage LNA as the front-end, followed by balanced mixer and post amplifiers alongwith necessary filters. The local oscillator chain is common between the two receivers and is derived from a temperature controlled crystal oscillator (TCXO) operating around 140 MHz and a multiplier chain. The outputs from the normal and redundant receivers are selected in the output hybrid and fed to the odd and even channel demultiplexers in the normal and extended C-bands.

The demultiplexers operate on the channel dropping concept and are based on dual-mode eight pole quasi-elliptic waveguide (TE – 111 mode) design. The twelfth

channel alone has twelve pole design to meet the additional skirt requirement to reduce tele command spurious. The individual channel filters have built in amplitude equalizers.

The separated signals of each channel are fed to solid state power amplifiers, which consist of an initial driver stage, variable gain setting attenuator and a high power amplifier. The final output stage is a 4/10W single ended device. All stages are made using GaAs FETs.

The outputs of the power amplifiers are combined in a manifold multiplexer, which combines non-contiguous channels. So odd and even channels are combined separately in two different multiplexers before feeding to the East and West antennas respectively. All the individual channel filters are based on dual mode six pole quasi-elliptic waveguide. A separate low pass filter is introduced between the normal C and extended C channels to minimise the interaction.

A harmonic rejection filter consisting of a low pass filter with good rejection at the harmonic frequencies is at the output of the multiplexers before feeding to the 1.7 m offset fed reflector antenna.

The expanded coverage channels are combined through a separate two channel contiguous multiplexer and fed to the transmit port of 70 cm C-band Tx/Rx antenna. The coverage provides a 8.2^0 beam. Two out of three redundancy is provided for the driver-TWTA sub-systems. The contiguous multiplexer is designed using filters of doubly terminated prototype with six sections, dual mode (TE 112 mode) and final tuning carried out in the assembled condition.

2.2.2 USES OF FSS CHANNELS

The C-band FSS channels are used for following purposes: -

(a) Single or multiple carrier analog/digital/data communications signals.

(b) Voice/data carriers operating in single channel per carrier (SCPC) mode.

The final output amplifier power supply specifications is compatible with the operation of TDMA signals with a frame length of multiples of 125 micro seconds upto 2 msecs.

2.2.3 FREQUENCY PLAN

	Normal Freq. Band	Ext. C-band
Uplink	5930 – 6410 MHz	6735 – 6975 MHz
Downlink	3705 – 4185 MHz	4510 – 4750 MHz

The difference between the Uplink and Downlink frequency for a given link is 2225 MHz. The frequency channelisation plan for INSAT 2C is given in Fig 2.3.

2.2.4 COVERAGE

Satellite transmit antenna patterns are such that all performance specifications are met over the coverage area as defined.

2.2.4.1 INSAT 2C

The primary coverage area is the area bounded by a continuous line composed of segments of great circle arc connection between the cities Srinagar, Jullunder, Jodhpur, Bhuj, Bombay, Goa, Ernakulam, Pondicherry, Bhubaneswar, Shillong, Gangtok and Leh. The secondary coverage area is the area outside the primary coverage area but lying within the geographical boundaries of the main land of India. The tertiary coverage area is the remaining part of the territory of India outside the secondary coverage area, including the islands. The primary area of coverage of INSAT 2C is given in Fig 2.4.

2.2.4.2 INSAT 2E

The entire mainland of India falls in the primary area of coverage of the satellite. Area of coverage of INSAT 2E is shown in Fig 2.5.

2.2.5 POLARISATION

The uplink and downlink signals at C-band operate in the linear polarisation mode. The cross polarisation isolation of transmit and receive C-band beams with

respect to their orthogonal polarisations is atleast 30 dB over the primary coverage areas.

2.2.6 GAIN SLOPE

The maximum gain slope within the usable bandwidth of any transmission channel does not exceed the values given in the Table 2.2. when the corresponding channel is illuminated at the saturation flux density. Input gain slope is measured between the input to the transponder and the input to the final power amplifier and includes the contribution of receive antenna. Total gain slope is the performance of the complete channel including the receive and transmit antennas.

Table 2.2

GAIN SLOPE SPECIFICATIONS

Portion Of the Channel	Gain slope (dB/MHz)	
	Chnls. 1-10, & 13 – 18	Chnls. 11 & 12
80 % BW	0.15	0.15
90 % BW	0.30	0.35
100% BW	0.50	0.80

2.2.7 GROUP DELAY

The group delay specifications are met over the usable bandwidth of the channels when the transponder is illuminated with flux densities equal to or less than that required to produce saturation. All the group delay values are relative with respect to the value at the centre of the channel. The total group delay including contribution from transmit and receive antenna are shown in Fig 2.6 for channels 11 & 12 and in Fig 2.7 for other channels. Over the middle 70% of the usable bandwidth the maximum group delay variation does not exceed 4.5 nsec/MHz.

2.2.8 AM-PM TRANSFER COEFFICIENT

Table 2.3

AM-PM TRANSFER COEFFICIENT SPECIFICAIONS

Total flux density of Two carriers, below the Single carrier Saturation flux density	AM-PM Transfer Coefficient (^{0}/dB)	
	for a TWTA ch.	for a SSPA ch.
0 dB	7.5	5.0
3 dB	8.5	5.0
6 dB	8.5	5.0
9 dB	7.5	4.0
12 dB	5.0	2.0
14 dB	3.0	1.0

2.2.9 SATELLITE LOCATIONS AND SEMI MAJOR AXIS

The locations, EIRP and approximate semi-major axis of satellites presently available with Doordarshan, India for TV broadcasting are given below:-

Satellite	EIRP (dBW)	Location (^{0}E)	Semi-major axis (Km)
INSAT 2C	39	93.5	42166.61
2DT	33	55.1	42164.62
INSAT 2E	36	83.0	42164.46
PAS-4	39	68.5	42164.27

These values have been used in various Link Budget calculations.

2.2.10 INTERMODULATION LEVELS

Any channel of the satellite is illuminated by two equal amplitude RF carriers, the level of the intermodulation products is as given in Table 2.4. The performance is met with any separation of the carriers with a minimum of 100 kHz, but within the usable bandwidth of the channels.

Table 2.4

THIRD ORDER INTERMODULATION LEVELS

Flux density of each of two carriers, below the Single carrier saturation Flux density	Third order Intermodulation level	
	TWTA	SSPA
3 dB	- 10 dB	- 12 dB
10 dB	- 16 dB	- 19 dB
17 dB	- 26 dB	- 30 dB

Table 2.1

INSAT 2C C-BAND TRANSPONDER PERFORMANCE SPECIFICATIONS

		Unit	Specification
1.	Receive frequency Band (Normal C)	MHz	5850 – 6410
	(Ext. C)	MHz	6735 – 6975
2.	Transmit frequency Band (Normal C)	MHz	3725 – 4185
	(Ext. C)	MHz	4510 – 4750
3.	Receive Polarisation		Linear, Horizontal
4.	Transmit Polarisation		Linear, Vertical
5.	Saturation flux density	dBW/m^2	-92 ± 2
6.	Receive G/T over primary	dB/K	-5.0
7.	Transmit EIRP		
	Channels – 1, 2, 3, 5, 7, 11 & 12	dBW	36
	- 9 & 10		36
	- 13 & 14		35
	- 4,6,8,15,16,17 & 18		32
8.	Usable Bandwidth	MHz	36
9.	AM-PM Transfer Coefficient(max)	^{0}/K	8.5
10.	Translation frequency	MHz	2225

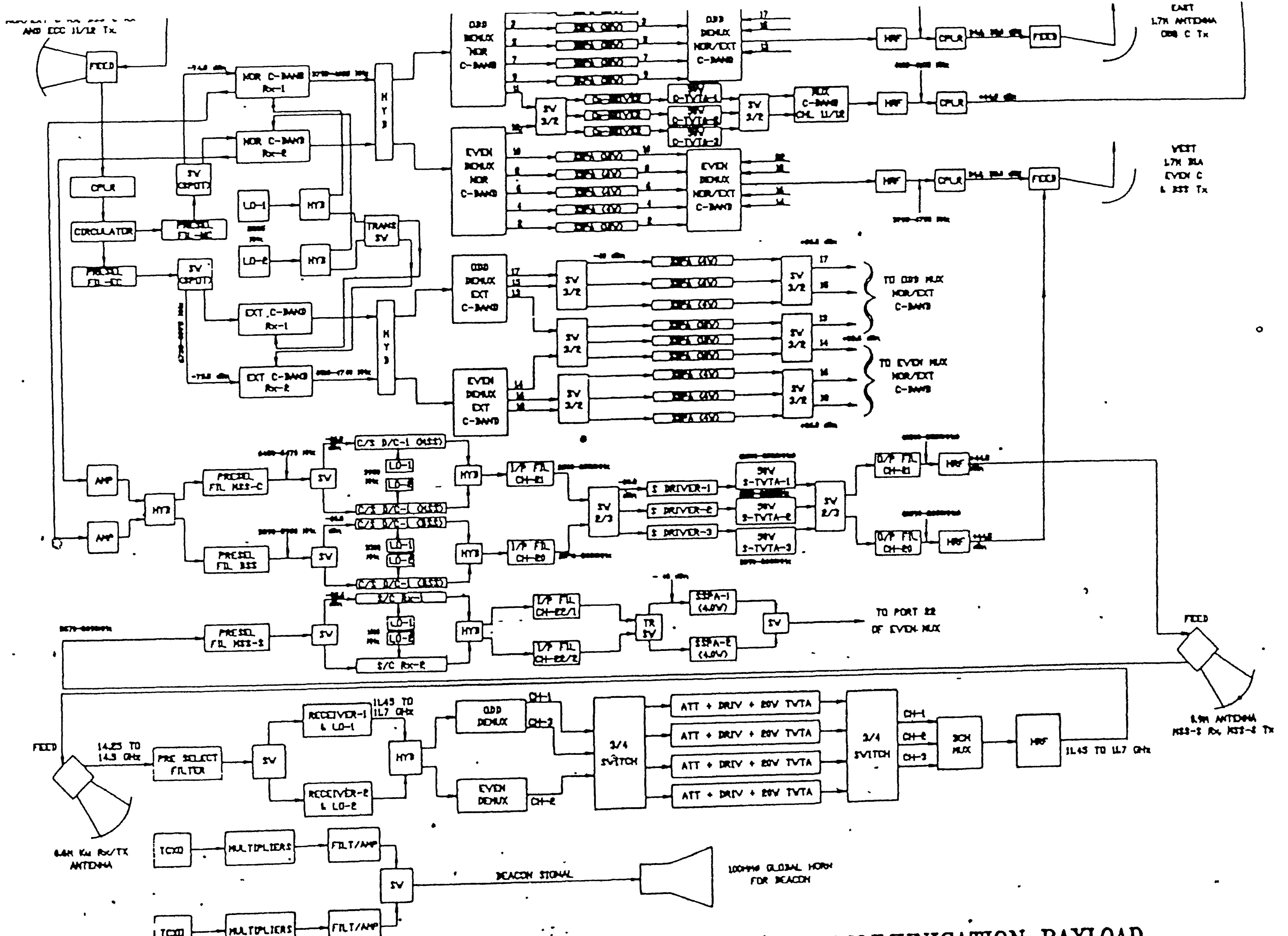
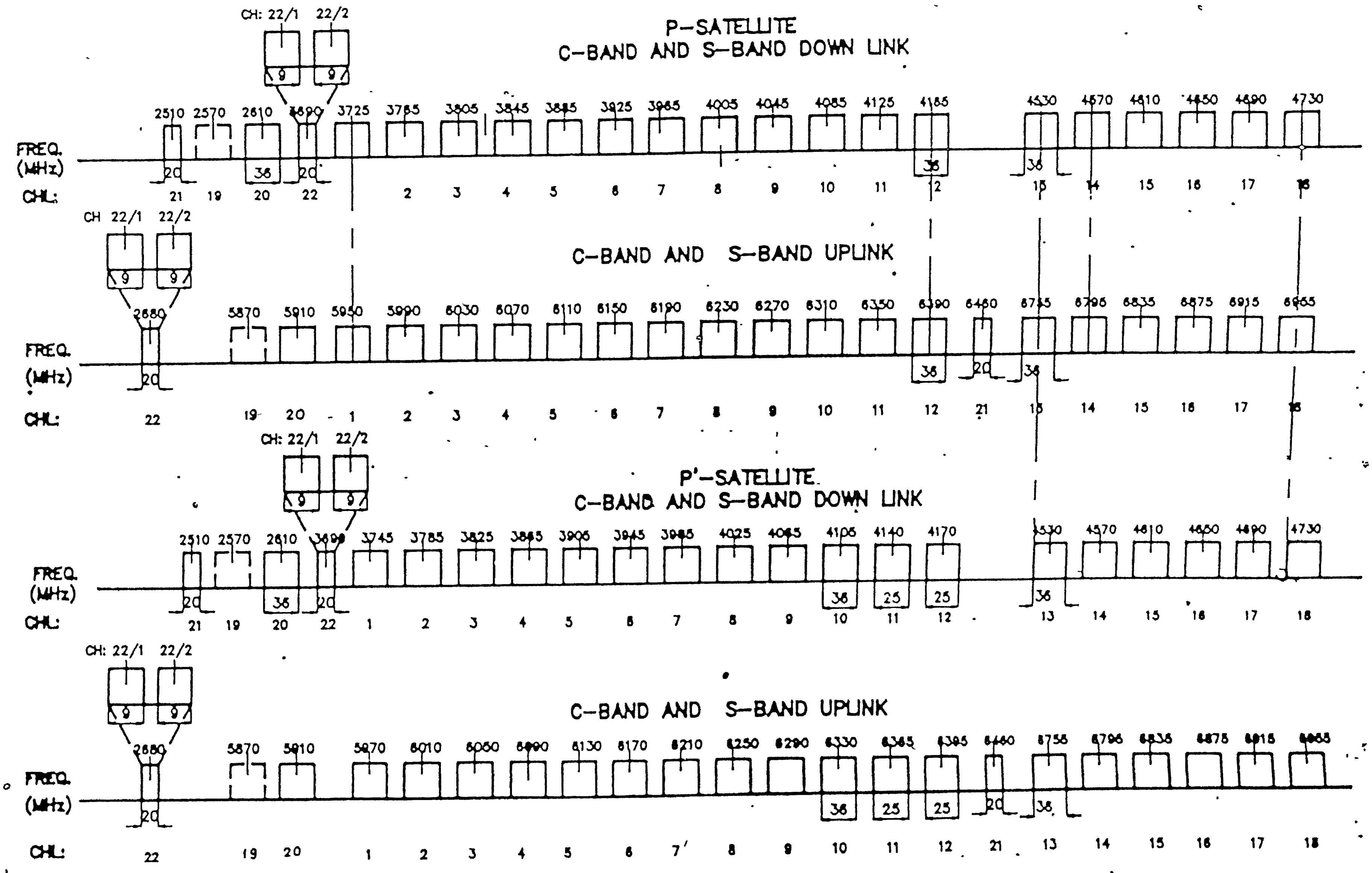


FIG.2.2BLOCK SCHEMATIC OF INSAT-2C/2D COMMUNICATION PAYLOAD

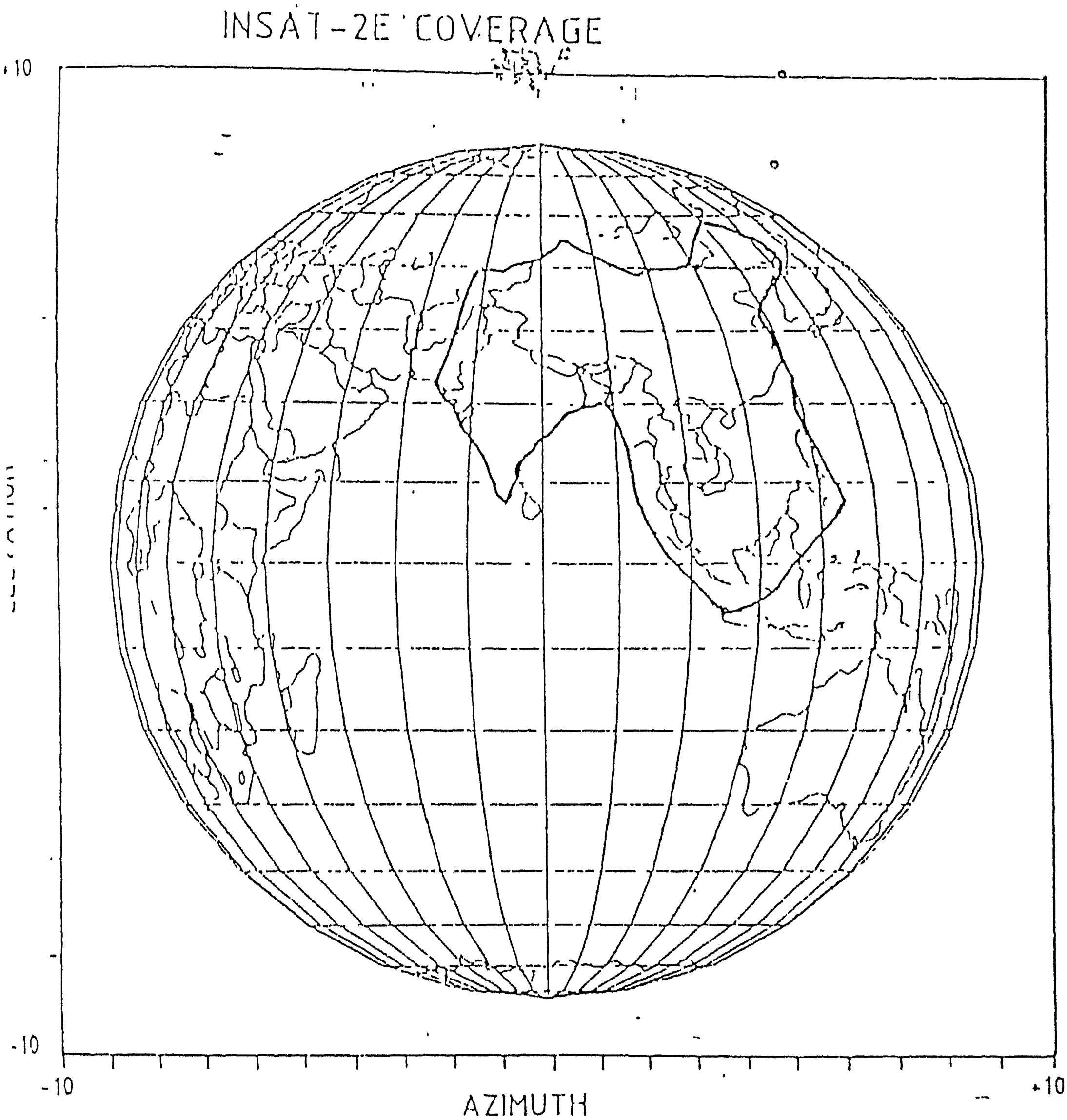
(NOR-C/EXT-C/S/KU-FSS/BSS/MSS)

FIG. 2.5 FREQUENCY PLAN– COMMUNICATION PAYLOAD
FOR INSAT – 2 C/D



DFT 4269410

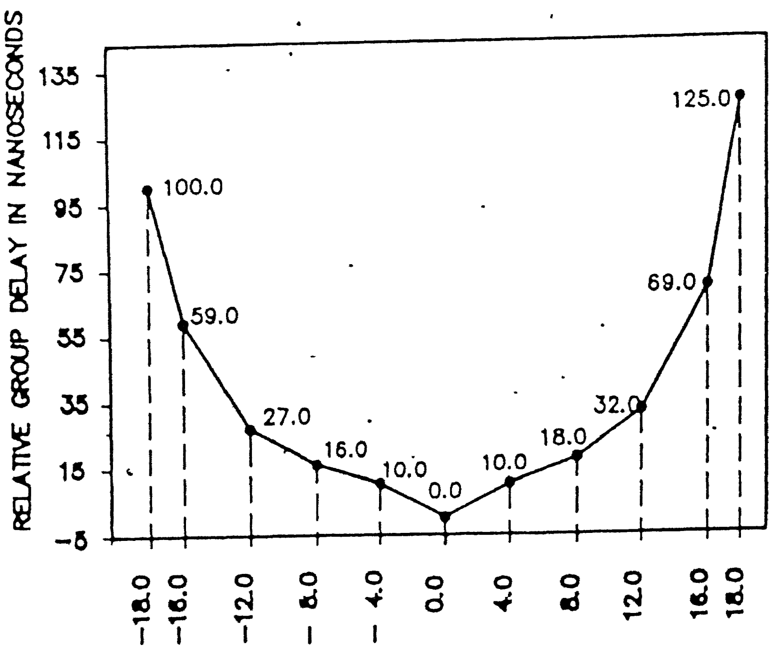
FIG. 2.4 INSAT PRIMARY COVERAGE AREA



COVERAGE POLYGON

LONG	LAT.
121 76	54 13
134.73	47.73
130 93	43.46
121 56	36.64
121 89	25.19
120.85	21 88
122.36	18.25
126 66	8 05
115.41	-3.70
105.86	-6.58
96 21	5.92
94.08	12.52
90.97	22 22
86 86	21.22
80 19	14.41
78 66	10.84
77.38	7.92
73.21	16.58
67 68	24.30
71.23	43.37
79.44	44.62
87.85	49.24
89.81	43.08
111.95	45.18
121 76	54.19

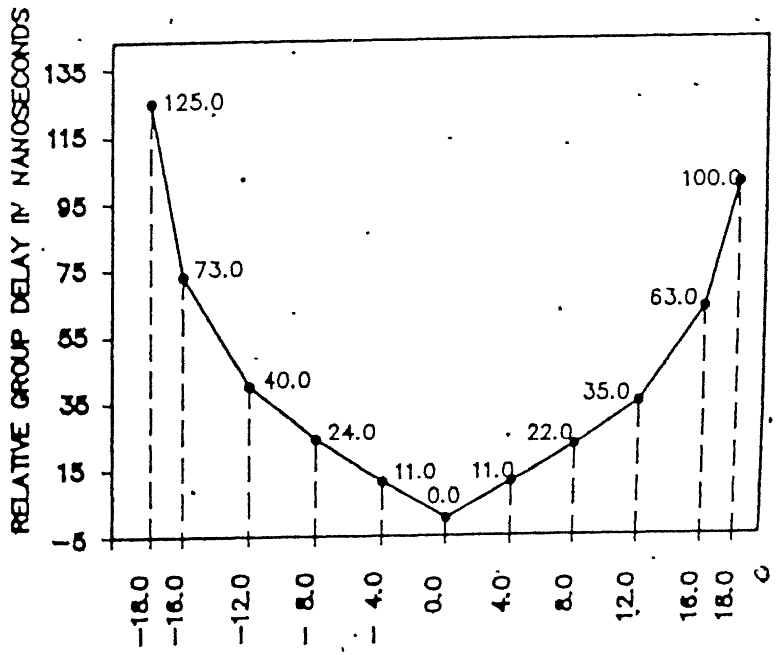
FIG 2.5 C-BAND ZONAL BEAM TRANSMIT COVERAGE POLYGON



FREQ. IN MHz FROM BAND CENTRE

TOTAL GROUP DELAY

FSS CHL-11

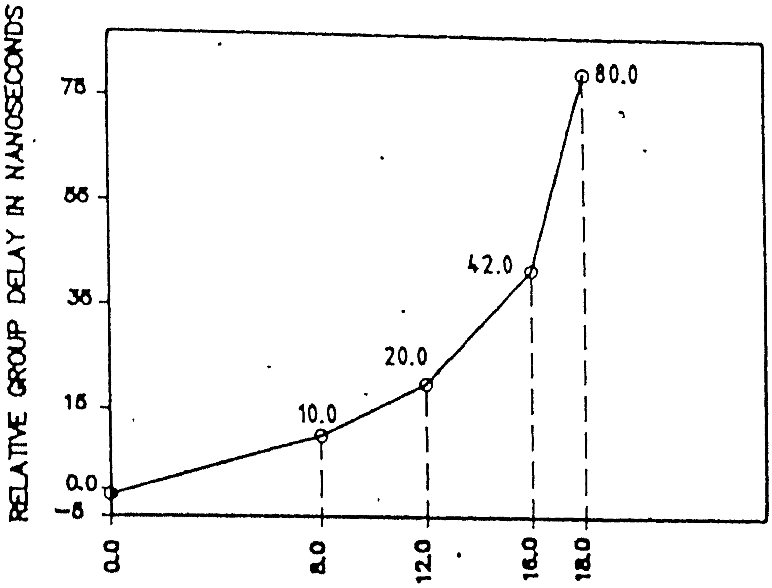


FREQ. IN MHz FROM BAND CENTRE

TOTAL GROUP DELAY

FSS CHL-12

FIG 2.6



FREQ. IN MHz FROM BAND CENTRE

TOTAL GROUP DELAY

FSS CHANNELS EXCEPT CHLS-11/12

FIG. 2.7

CHAPTER 3

Link Budget Considerations

3.0 INTRODUCTION

In a satellite link it is proven that a free space path loss analysis, together with known loss parameters provide very accurate quality prediction results. The various considerations that play a significant role in Link Budget analysis are given in this chapter. These also form an integral part of digital satellite communication link budget.

3.1 ATMOSPHERIC ABSORPTION AND RAIN LOSSES

Atmospheric absorption losses are comparatively low for systems operating below 10 GHz [3]. These losses vary with frequency, elevation angle and altitude. For 4 GHz, downlink the recommended values are 0.5 dB for 5° elevation angle and 0.25 for 10°, both values being for sea level.

Excess attenuation due to rainfall also varies with frequency, elevation and altitude. Recommended estimates are 0.5 dB at 5° elevation angle for 4 GHz downlink band, 0.25 at 10° and 0.15 dB at 15° with similar values for the 6 GHz uplink.

The uplink absorption and rain losses can be compensated by a higher EIRP of the transmitting earth station. Excess downlink losses are difficult to manage since the downlink is power limited. If in any region the downlink losses are very high then a trade off with acceptable service is to be made since the overall link performance will be degraded.

3.2 POLARISATION AND POINTING LOSSES

Polarisation losses, if not available may be taken as 0.5 dB in both uplink and downlink [3].

Pointing losses for satellite and terminal also have to be considered. However, if the satellite covers the entire region in its primary area then satellite pointing losses

may be neglected, 0.5 dB pointing loss for the terminals have to be taken for both uplink and downlink.

3.3 BANDWIDTH LIMITATION

This is the degradation due to the limited bandwidth of the transponder input multiplexer (IMUX) and output multiplexer (OMUX) filters, mainly the OMUX filter. It depends on the BW/R_s(ratio of bandwidth to symbol rate) ratio and is around 0.4 dB for reasonable BW/R_s ratios [10].

3.4 NON-LINEARITIES CAUSING INTER SYMBOL INTERFERENCE (ISI)

Non-linearities in the transponder TWTA can cause ISI. The level of this interference depends on the TWTA operating point and is a maximum at saturation point. Typically, the degradation due to ISI lies in the range of 0 to 0.7 dB [10].

3.5 POWER REDUCTION DUE TO NON-LINEARITIES

This effect which is different from ISI, is caused due to the appearance of secondary lobes of the signal spectrum, caused by non-linear behaviour of TWTA and the filtering that the signal suffers at the OMUX. The power reduction due to this effect is around 0.9 dB when the TWTA is operating at saturation point [10].

3.6 NOISE BANDWIDTH INCREASE DUE TO CODING

The channel coding causes the noise bandwidth of the signal, to increase by a factor of $10 \log_{10} 4/3$ (i.e. around 1.25 dB). This increase is taken into account when calculating E_b/N_0.

3.7 MODEM IMPLEMENTATION MARGIN

This is the difference between the theoretical performance and the real performance of modems working back to back. A value of 0.8 dB (as used in the DVB-SAT. specification) may be taken as reference [10].

3.8 MODULATION

The correct choice of a modulation technique depends on the design requirements and constraints. In a very-small-aperture-terminal (VSAT) satellite network BPSK modulation is preferred because the downlink from the network hub is typically power limited by the total EIRP offered by the transponder. On satellite uplink from the VSAT it is noise limited because of the low EIRP of the ground stations from low antenna gain. Therefore, bandwidth efficiency of the modulation is less important than the robustness and power efficiency of the modulation. In a large satellite network where the physical dimensions of the antenna aperture are high, QPSK is preferred. If however, the dimensions of the receiver antenna aperture are small but the downlink EIRP limitation is not a problem then QPSK many be used. Apart from the additional relative implementation simplicity advantage, QPSK is used most widely since it has good power and bandwidth efficiency.

PSK is the most popular modulation scheme employed in digital satellite links. The output of the PSK modulator assumes only a finite number of levels (2 or powers of 2). A two level PSK (BPSK), four-level PSK (QPSK), eight level PSK (8-PSK) and so forth.

By increasing the number 'L' of phase modulation levels the required RF bandwidth decreases (transmission capacity in terms of b/s/Hz increases) but the error performance at a given C/N worsens.

The spectral density of the PSK signal is determined by the Fourier transform of the NRZ sequence, centered across the carrier frequency f_c and is given by

$$S_{PSK}(f) = \frac{P}{S}\left\{\frac{Sin[\pi(f-f_c)/S]}{\pi(f-f_c)/S}\right\}^2$$

where

P =	Carrier Power	
S =	R/K	= Symbol rate
K =	$\log_2 L$	
R =	Bit transmission rate	

By increasing the number of phase levels L the modulated spectrum gets narrower. The RF spectrum envelope is controlled by the symbol interval T=1/S. The (sin x)/x spectrum main lobe extends from f_c-S to f_c+ S.

Hence T_s = K/R, where R is the bit rate K=1 (BPSK) gives a main lobe in the (sin x)/x spectrum 2R wide, extending from f_c-R to f_c+R, K=2 (QPSK) gives a mainlobe extending from f_c-R/2 to f_c+R/2, K=3 (8 PSK) has a mainlobe extending from f_c-R/3 to f_c+R/3 and so on.

A symbol rate 'S' can be transmitted and received without ISI using an f_N=S/2 (Hz) low pass equivalent cutoff frequency (Nyquist frequency). Thus a 'R' bps information signal can be transmitted through a channel of width

$$2f_N = S = \frac{1}{T} = \frac{R}{K}$$

If filters having a roll off factor α are used for pulse shaping then excess bandwidth required is:

$$BW_{OCC} = 2f_N = \frac{R}{K}(1+\alpha)$$

For roll-off factor $\alpha = 0.38$

$$BW_{OCC} = 1.38x\frac{1}{Ts}$$

BPSK	BW_{OCC}	=	1.38 x	transmission rate
QPSK	BW_{OCC}	=	0.69 x	transmission rate
8-PSK	BW_{OCC}	=	0.46 x	transmission rate

where the transmission rate is calculated as

$$Transmission \quad rate = \frac{Information \quad rate}{FEC \quad Code \quad rate}$$

Gray coding is used with QPSK modulators so that the decision errors are made only between adjacent states. This ensures that a single symbol error corresponds to a single bit error. The property of gray code that is used, is that the consecutive dibits are mapped such that the adjacent symbols differ by only one bit.

The bit error rate for BPSK and QPSK depends on E_b/N_0 and is given by

$$P_e = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_o}}\right)$$

3.9 CHANNEL CODING

The performance improvement provided by channel coding is called coding gain. It is defined as the amount (in dB) by which the signal power required to obtain a given BER may be decreased when the signal is coded using the same transmission time and thus a large BW and symbol rate. It is the difference in the E_b/N_o values necessary to obtain the specified level of BER with and without coding. The operating point of the FEC codes is usually centered around the awkward knee of the E_b/N_o and BER curve, $E_b/N_o = 4$ to 10 dB.

In a satellite link, which can be modeled as Gaussian noise channel the bit error occurs randomly and in bursts. A concatenated RS Convolutional Viterbi code is highly popular for such a channel. It consists of an inner code whose task is to correct random errors and an outer code, which can correct residual random errors plus burst errors. Fig.3.1 shows the concatenation of an RS code with a convolutional-Viterbi code [4].

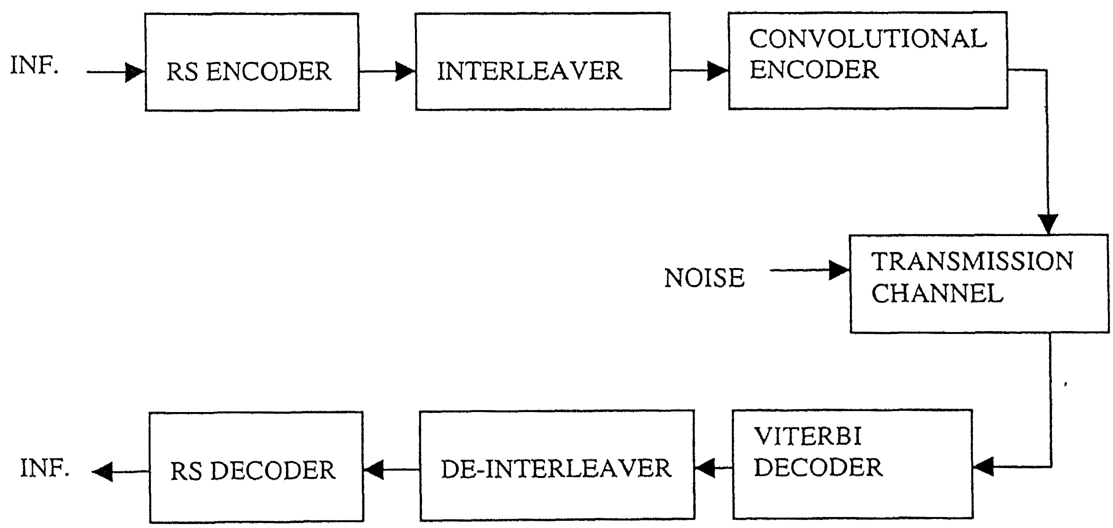


Fig. 3.1. Concatenated RS Convolutional Viterbi Code

The Virterbi algorithm is the most popular decoding method for convolutional codes for obtaining reasonable coding gains in an AWGN environment. Concatenated RS-convolutional soft Viterbi codes along with interleaving offer coding gains upto 7 dB. The use of an RS outer code is generally mandatory for intercomputer links requiring a BER of 10^{-9}-10^{-10}.

An RS (n,k) code encodes m-bit symbols into blocks consisting of $n=2^m-1$ symbols, i.e. $m(2^m-1)$ bits where $m \geq 1$. Encoding algorithm expands a block of 'k' symbols to 'n' symbols by adding 'n-k' redundant symbols. When 'm' is an integer power of two, the 'm' bit symbols are called bytes. A popular value of 'm' is 8. Typically in DVB an RS (204, 188) is used.

Error correcting capability t of an RS code is given by

$$t = \frac{n-k}{2}$$

In a convolutional code the code rate is given by the ratio $r = \frac{k}{n}$ where the 'n' output bits are generated from 'k' input bits taken as a group. The output bits are generated according to logic processes. An important parameter which determines the number of input bits required to be grouped simultaneously by the logical circuits is the constraint length and is equal to 7 for a typical DVB satellite channel. The code rates can be 1/2, 2/3, 3/4, 5/6 & 7/8. The total code rate is given by:

Total Code Rate = Inner Code Rate x Outer Code Rate

Typical detection thresholds for present commercial receivers are given below:

Table 3.1

BER better than	E_b/N_o(dB) Rate=1/2 FEC	E_b/N_o(dB) Rate=3/4 FEC
10^{-6}	4.1	5.6
10^{-7}	4.2	5.8
10^{-8}	4.4	6.0
10^{-9}	5.0	6.3

3.10 INTERMODULATION DISTORTION

The principal source of intermodulation (IM) noise in a satellite transponder is the final amplifier, which may typically be a TWTA or SSPA. In order to bring the IM products to an acceptable level and then not degrade the system C/N_0 due to poor $C/N)_i$ performance, the total power of the uplink must be "backed off" or reduced, commonly to a $C/N)_i$ of 20 dB or better. This results in a reduction in downlink EIRP. Their exact relationship can be obtained from the input power reduction versus output power curve. Typically the $C/N)_i$ ratio increases rapidly with increasing input back off.

Transponder non-linearities can be assumed as having instantaneous transfer characteristic as a Taylor series:

$$e_0 = a_1 e + a_3 e^3 + \ldots\ldots\ldots\ldots \ldots\ldots\ldots\ldots + a_k e^k \qquad (1)$$

where 'e' is the instantaneous input voltage and e_0 is the resulting output voltage. The coefficients a_k alternate in sign. For an input of n equal carriers.

$$e = \sum_{i=1}^{n} A \; Cos \; w_i t \qquad (2)$$

with a total input power P_i (normalized to 1Ω circuit impedance) of $\frac{1}{2} n A^2$.

By substituting (2) in (1) we get for each of n equal carriers

$$An = a_1 \sqrt{\frac{2P_i}{n}} \left[1 + 3\frac{a_3}{a_1}\frac{P_i}{n}\left(n - \frac{1}{2}\right) + 15\frac{a_5}{a_1}\left(\frac{Pi}{n}\right)^2 \left(n^2 - \frac{3}{2}n + \frac{2}{3}\right) + \ldots\ldots \right]$$

and as $n \to \infty$

$$A_\infty = a_1 \sqrt{\frac{2P_i}{n}} \left(1 + 3\frac{a_3}{a_1} P_i + 15\frac{a_5}{a_1} P_i^2 + 105\frac{a_7}{a_1} P_i^3 + \ldots\ldots \right)$$

The form $a_1 \sqrt{2P_i/n}$ is the linear component of the transfer characteristics and the form in parentheses represent the non-linear or "compression" factor $F_n(P_i)$.

The intermodulation products are:

Of the form ($2f_1$-f_2) whose amplitudes are:

$$I_n = \frac{3}{4} a_3 \left(\frac{2P_t}{n} \right)^{3/2} \left\{ 1 + \frac{2}{3} \frac{a_5}{a_3} \frac{P_t}{n} [12.5 + 15(n-2)] + \ldots\ldots\ldots\ldots \right\}$$

Of the form $(f_1 + f_2 - f_3)$ whose amplitudes are:

$$I_n' = \frac{3}{2} a_3 \left(\frac{2P_2}{n} \right)^{3/2} \left[1 + 10 \frac{a_5}{a_3} \frac{P_t}{n} [\frac{3}{2} + (n-3)] + \ldots\ldots\ldots\ldots \right]$$

In addition to the amplitude of each product we also have to calculate their number.

With little approximation we can calculate $\left(\frac{C}{I} \right)_n$ as the ratio of single central carrier to the total of all the products falling on it and is given by

$$\left(\frac{C}{I} \right)_n = \frac{n^2}{6(n-1)(n-2)} \left[\sqrt{\left(\frac{C}{I} \right)_2} + \left(\frac{n-2}{n} \right) \right]^2$$

where $\left(\frac{C}{I} \right)_2$ is the value of third intermodulation products usually quoted on the data sheets of amplifiers of transponders by the manufacturer. Typical intermodulation products given in Chapter 2 for INSAT-2C have been used in calculation for multiple carriers.

3.11 AM-AM AND AM-PM CONVERSION

As a carrier passes through a TWT amplifier, it produces amplitude modulation from gain slope anomalies and phase modulation from AM-PM conversion effect. The effect of AM-AM and AM-PM conversion arises since bandpass filters are used to limit the signal spectrum of the PSK modulated signal and the non-linearity of the amplifier. Due to envelope fluctuations the amplifier distorts the signal and a system performance

degradation results. Amplitude variations may be present even when using a constant envelope modulation technique because of the ripple in the passband of the bandpass filters used in transponders.

The AM-PM conversions are proportional to and specified by the parameter known as AM-PM conversion co-efficient. This parameter is specified in degrees of phase shift per decibel of amplitude change and is a function of the input level. The value of the parameter decreases with increasing input back off and is very significant at saturation.

The effect of these distortion is to decrease the BER and to maintain a specified BER higher values of E_b/N_0 are required.

3.12 GROUP DELAY DISTORTION

Group delay is defined as the gradient of signal phase response with respect to frequency response. Group delay for a frequency component for a system is the transit time for that frequency component to go through the system. Since a signal contains a wide range of frequency components, then due to group delay, the phase relationship of the signal spectrum components is not preserved. In group delay distortion the primary concern is the variation of the length of transmit time with respect to frequency. Total group delay distortion comprises quadratic group delay distortion and linear group delay distortion. The transmission impairment depends on the ratio d/T_s, where d is the maximum group delay at the edge of the band and T_s is the symbol duration and creates a need for additional E_b/N_0 because of inter-symbol-interference (ISI) introduced.

Group delay equalization for the satellite channel has to be done at the respective transmitting and receiving earth stations using equalization masks.

3.13 REFERENCE VALUES FOR VARIOUS NON-LINEARITIES

The reference values to adopt when planning DVB (using satellites) services are detailed in Table 3.2. They represent the most accurate assumption for the performance of DVB (satellite) equipment and have been obtained from the work carried out in the Euro-Image project, Co-ordinated by EBU [10]. The required E_b/N_o values take into account the contribution from AWGN, modem implementation margin (0.8dB), noise bandwidth increase, bandwidth limitation degradation and non-linearities (ISI). Power

reduction due to non-linearities and intra system interference losses are not included in the required E_b/N_o values.

Table 3.2

Parameter	Euro Image reference Values (dB)
Bandwidth limitation degradation	0.1-0.4
Non linearities (ISI) degradation	0.0-0.7
Interference losses (Intrasystem)	0.0-0.3
Power reduction due to non-linearities	0.9
Noise bandwidth increase $10\log_{10}(4/3)$	1.25
Modem Implementation margin	0.8
Required E_b/N_o	
FEC ½	5.5
FEC 2/3	6.0
FEC ¾	6.6
FEC 5/6	7.2
FEC 7/8	7.9

CHAPTER 4

Link Budget Calculations

4.0 INTRODUCTION

Link budget calculations have been done using satellites 2DT and INSAT-2E located at 55.1^0 E and 83^0 E, respectively. The satellite 2DT has been chosen to give a worst case scenario since it is located farthest from the Indian mainland. INSAT-2E is chosen because of its strategic location over Indian mainland and the fact that it will be available for exploitation in near future.

The uplink is considered between Kanpur and the satellites and for downlink VSAT terminals at Mumbai, Bangalore, Srinagar and Guwahati are considered. The cities have been considered for calculations because of their geographical locations on Indian subcontinent and the fact that they fall in the primary area of coverage of both the satellites. List of formulas used in the calculations is given in Appendix placed at the end of the chapter.

4.1 SIMULCASTING

In simulcasting limited power and bandwidth is available from the satellite. The downlink digital EIRP is taken as 25 dBW and the bandwidth available as 6 MHz. A typical link budget between Kanpur and Bangalore for a 5 Mbps data link using satellite 2DT is as follows :

1.	**Transmit E/S**		Units
a.	E/S name	Kanpur	
b.	Antenna Diameter	6.3	m
c.	Antenna Gain	49.38	dB
d.	Latitude	26 28	^{o} N
e.	Longitude	80.24	^{o} E
f.	Elevation	48.51	degrees
g.	Azimuth	226.66	degrees
h.	Distance to Satellite	37174.69	Km

2. Receive E/S

a.	E/S name	Bangalore	
b.	Antenna Diameter	2.4	m
c.	G/T	17.6	dB/K
d.	Latitude	12.58	°N
e.	Longitude	77.38	°E
f	Elevation	60.27	degrees
g.	Azimuth	242	degrees
h.	Distance to Satellite	36507.33	Km

3. Carrier Characteristics

a.	Uplink frequency	6	GHz
b.	Downlink frequency	4	GHz
c.	Data Rate	5	Mbps
d.	FEC Code	0.75	
e.	Transmission Rate	6 67	Mbps
f.	Carrier Noise Bandwidth	4.6023	MHz
g.	No. of Carriers	1	

4. U/L and D/L EIRP

a.	D/L EIRP	25	dBW
b.	Transponder Saturation EIRP	33	dBW
c.	Output Back Off	-8	dB
d.	TWT I/O back off difference	1.5	dB
e.	Input back off	-9.5	dB
f.	Transponder SFD	-84	dBW/m^2
g.	Flux Density Arriving at Satellite	-93.5	dBW/m^2
h.	Uplink Losses	1.5	dB
i.	U/L Path Loss	199.42	dB
j.	Gain of $1m^2$ antenna	37	dBW/m^2
k.	U/L EIRP	70.42	dB
l.	U/L Power	127.06	Watt

5. Uplink Budget

a.	U/LEIRP	70.42	dB
b.	Losses (Rainfall, atm attenuation, Polarisation and Pointing)	1.5	dB
c.	Satellite G/T	-6	dB/K
d	$C/T)_U$, thermal	-136.5	dBW/K

6. Downlink Budget

a.	D/L EIRP	25	dBW
b.	Losses	1.5	dB
c.	Path Loss	195.74	dB
d.	Receiver G/T	17.6	dB/K
e.	$C/T)_D$, thermal	-154.64	dBW/K

7. $C/T)_I$, Interference

a.	C/I	20	dB
b.	$C/T)_I$	-141.97	dBW/K

8. Total C/T

a.	Overall C/T	-154.93	dB
b.	Data Rate	67	dB
c.	E_b/N_o	6 67	dB

The elevation angle, azimuth angle and distance to satellite for 2DT are given in Table 4.1 below :

Table 4.1

S No.	Location	Elevation (degrees)	Azimuth (degrees)	Distance (Km)
1.	Kanpur	48.51	226.66	37174.69
2.	Bombay	60.47	224.64	36497.47
3.	Bangalore	60.27	242	36507.33
4.	Guwahati	39.62	239.15	37810.70
5.	Srinagar	45.28	212.18	37393.51

The elevation angle, azimuth angle and distance to satellite for INSAT 2E are given in Table 4.2 below :

Table 4.2

S No.	Location	Elevation (degrees)	Azimuth (degrees)	Distance (Km)
1.	Kanpur	59.1	172.67	36565.60
2.	Bombay	64.87	152.59	36303.10
3.	Bangalore	73.58	153.79	36007.98
4.	Guwahati	58.21	197.65	36609.06
5.	Srinagar	49.24	164 23	37126.97

E_b/N_o values obtained for various data rates for satellite 2DT are shown in Table 4.3 below :

Table 4.3

S.No.	Data Rate (Mbps)	BW (MHz)	Mumbai (dB)	Bangalore (dB)	Guwahati (dB)	Srinagar (dB)
1.	1	0.92	12.87	12.87	12.63	12.71
2.	2	1.84	10.34	10.34	10.08	10.16
3.	3	2.76	8.75	8.75	8.48	8.57
4.	4	3.68	7.59	7.59	7.32	7.40
5.	5	4.6	6.67	6.67	6.39	6.48

E_b/N_o values obtained for various data rates for INSAT 2E are shown in Table 4.4 below :

Table 4.4

S.No.	Data Rate (Mbps)	BW (MHz)	Mumbai (dB)	Bangalore (dB)	Guwahati (dB)	Srinagar (dB)
1.	1	0.92	12.98	13.04	12.92	12.83
2.	2	1.84	10.42	10.49	10.33	10.25
3.	3	2.76	8.82	8.94	8.76	8.65
4.	4	3.68	7.66	7.72	7.59	7.48
5.	5	4.6	6.73	6.79	6.66	6.55

Assumptions

1. The I/O back off difference has been assumed as 1.5. It may be obtained from a typical I/O curve or may be specified for a TWTA by the manufacturer.

2. C/I, the carrier-to-interference ratio is taken as 20 dB.

3. Intermodulation distortion is not considered as there are only two carriers per transponder.

4.1.1 HIGHER POWER ALLOCATION IN SIMULCASTING

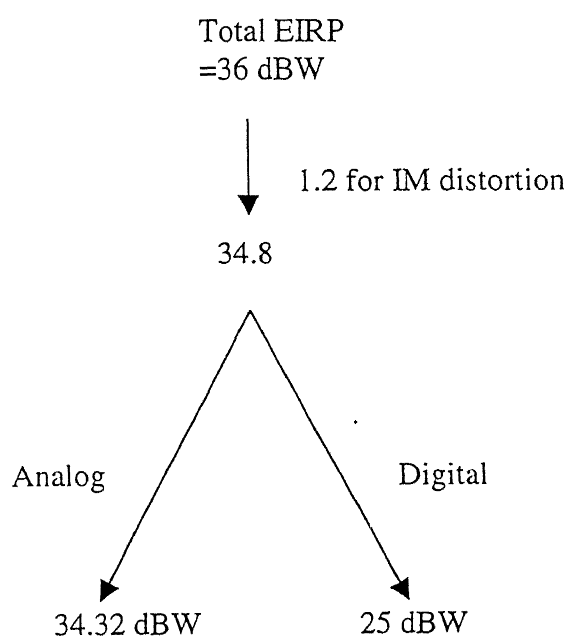
In case of INSAT 2E the total saturation EIRP is 36 dBW. Higher power than 25 dBW for digital carrier could be requested to achieve better results in E_b/N_o values. Typical calculations for 5 Mbps data rates for Mumbai with increased digital EIRP are given in Table 4.5.

Table 4.5

S. No.	D/L EIRP (dBW)	E_b/N_o(dB)
1.	26	6.82
2	27	7.76
3.	28	8.69
4.	29	9.6
5.	30	10.49

4.1.3 POWER SHARING IN SIMULCASTING

Power sharing done between the analog and digital carrier in simulcasting is as follows :



We can see that for INSAT 2E the analog carrier EIRP is 34.32 dBW. In case of 2DT where the total EIRP is 33 dBW and after deducting 22 dBW for digital EIRP and 1.5 dB for intermodulation distortion, Doordarshan, India is carrying out analog transmission with EIRP of 29.5 dBW. The extra power in analog carrier of INSAT 2E

may be shared with the digital carrier power which then can be increased from 25 dBW to higher values. A higher D/L digital EIRP will result in better E_b/N_o ratios at the receiver. Therefore, maximum power possible without deteriorating the analog signal quality should be requested for digital carrier.

4.2 FREQUENCY DIVISION MULTIPLE ACCESS

In digital broadcasting to transmit current "NTSC/PAL/SECAM' quality a bit rate of 2 5-6 Mbps is required.

Thus assuming that the entire transponder (36 MHz) is available and five carriers having data rate of 6 Mbps access it simultaneously.

Data rate	=	6 Mbps	=	67.78 dB
Bandwidth per carrier	=	5.52 MHz		

Assuming an input back off of 7 dB since FDMA operation is generally optimized for an output back off of 5 – 8 dB.

I/P back off	=	- 7 dB
I/O back off difference	=	1.5 dB
O/P back off	=	5.5 dB

For n = 5 carriers

Downlink EIRP per carrier = 23.51 dBW

The uplink EIRP per carrier is calculated as :

EIRP/Carrier	23.51	dBW
Satellite Saturation EIRP	36	dBW
O/P Back off	-12.49	dB
I/O Back Off Difference	1.5	dB
I/P Back Off	-13.99	dB
SFD	-94	dBW/m^2
Flux Density at Satellite	-107.99	dBW/m^2
Uplink EIRP	56.01	dBW

$$\left.\frac{C}{T}\right)_{I} = -141.18 \quad \text{dBW/K}$$

$$\left.\frac{C}{T}\right)_{I} = -149 \quad \text{dBW/K}$$

$$\left.\frac{C}{T}\right)_{U} = -150.94 \quad \text{dBW/K}$$

$$\left.\frac{C}{T}\right)_{D} = -156.14 \quad \text{dBW/K}$$

$$\left.\frac{C}{T}\right)_{IM} = -157.98 \quad \text{dBW/K}$$

and the system E_b/N_0 is given by

$$\frac{E_b}{N_o} = 2.84 \text{ dB}$$

If reception is done with a 6.2 m dish with G/T=25.5 dB/K, then

$$\frac{E_b}{N_o} = 6.3 \text{ dB}$$

For case n = 7 Data Rate = 5 Mbps

<u>for a VSAT terminal</u>

$$\frac{E_b}{N_o} = 2.31 \text{ dB}$$

<u>for a receiving dish of 6.2 m</u>

$$\frac{E_b}{N_o} = 5.93 \text{ dB}$$

If however the receiving dish is small i.e. VSAT then the data rate can be decreased for a higher value of $\frac{E_b}{N_o}$. Typical values of $\frac{E_b}{N_o}$ calculated for n=5 and data rate = 3 Mbps is 5.26 dB.

4.3 TIME DIVISION MULTIPLE ACCESS.

TDMA channel capacity is given by

R_b = $W + B - C_w$

where

R_b = link rate in dB

W = Satellite transponder Bandwidth in dB

B = Bit rate to symbol rate ratio expressed in dB

C_w = Ratio of the transponder bandwidth to the possible band limited Symbol rate through the transponder

for a 36 MHz transponder

W = 36 MHz = 75.56 dB

B = 3 dB for QPSK modulation

C_w = 1.4 for filters with roll off factor $\alpha = 0.38$

R_b = 75.56 + 3 − 1.4

= 77.16 dB

= 52 Mbps = 26 Msps for QPSK modulation

4.3.1 FRAME EFFICIENCY

The frame efficiency of a TDMA link is given by :

$$\eta = \frac{R_b T_r - K b_p - N b_t - (N+K)\dot{b}_g}{R_b T_F}$$

where

T_F = 2 ms

K = No. of users = 16 (assumed)

b_p = no. of bits in preamble of off traffic burst
= 280 (assumed)

N = No. of reference earth stations
= 2 (assumed)

b_r = no. of bits in reference burst
= 288 bits (assumed)

b_g = no. of bits in guard time
= 60 bits (assumed) for a guard time of nearly 1 μs.

η = 94.1 %

For the frame efficiency calculation a typical network has been assumed. The number of bits used in preamble of traffic bursts, reference bursts and guard times have been taken from that of an Intelsat network using a transponder of 72 MHz and TDMA bit rate of 120.832 Mbps. The values used in the calculation have been halved since the transponder bandwidth in our case is 36 MHz.

4.3.2 CALCULATION OF E_b/N_0

$$\frac{E_b}{N_o} = \text{EIRP} - \text{Losses} - \text{Path loss} + (G/T)_{ES} + 228.6 - 10\log_{10}(\text{Bit rate})$$

$\frac{E_b}{N_o}$ calculated for various data rates is given in Table 4.6.

Table 4 6

S. No.	Data Rate (Mbps)	E_b/N_o (dB)
1.	52	7.79
2.	50	7.96
3.	45	8.42
4.	40	8.93

4.3.3 LENGTH OF TRAFFIC BURST

The total length of the traffic burst, T_{TR} is given by :

$$T_{TR} = \frac{R_{data} T_f + b_p}{R_b}$$

R_{data} is the bit rate a traffic station wishes to support. If the number of users is more then T_{TR} allotted to a traffic station may be less and thus it will support a lower data rate thereby having a reduced throughput.

For $T_F = 2$ ms & $R_b = 52$ Mbps

The length of total traffic burst for different data rates is given in Table 4.7. As T_{TR} increases, the number of traffic earth stations, K, reduces.

Table 4.7

R_{data} (Mbps)	T_{TR}
1	43.8 µs
2	82.3 µs
3	120.7 µs
4	159.2 µs
5	197.6 µs

Appendix

Formulas Used in Calculations

1. Antenna Gain (η=0.55)

   $G = 10 \log_{10} 60.72 f^2 D^2$

   where

   f $\rightarrow$ frequency in GHz

   D $\rightarrow$ Ant. Diameter in meter

2. $\phi = \text{EIRP} - [\text{Losses}] + \left[\frac{4\pi}{\lambda^2}\right]$ dBW/m^2

   where

   ϕ = actual flux density at the satellite

   $\left[\frac{4\pi}{\lambda^2}\right]$ is the gain of 1m^2 of receiving antenna (incorporated to convert power into flux density)

   Losses = path loss + system losses

   λ = wavelength of uplink signal

3. Path loss

   Path loss = 92 45 + 20 $\log_{10}$ f + 20 $\log_{10}$ d dB

   where

   f $\rightarrow$ freq in GHz

   d $\rightarrow$ Distance in Km.

4. $$\left.\frac{C}{T}\right)_I = \frac{C}{I} + 10\log_{10} BW - 228.6$$

5. $$\left.\frac{C}{T}\right)_{Total} = \left.\frac{C}{T}\right)_U^{-1} + \left.\frac{C}{T}\right)_D^{-1} + \left.\frac{C}{T}\right)_I^{-1} + \left.\frac{C}{T}\right)_I^{-1}$$

6. Central angle 'γ'

$\cos\gamma = \cos(L_e)\cos(l_s - l_e)$

L_e = earth station latitude

l_s = longitude of satellite

l_e = longitude of earth station

7. Distance to satellite 'd'

$$d = \sqrt{h^2 + 2R_E(R_E + h)(1 - \cos(L_e)\cos(l_s - l_e))}$$

where

h = height of satellite above earth's surface

R_E = radius of earth = 6378 Km

R_E+h = semi major axis

8. Azimuth angle 'Az' may be calculated from

$$\alpha = 2\tan^{-1}\left\{\frac{\sin(s-\gamma)\sin(s-|L_e|)}{\sin(s)\sin(s-|l_e - l_s|)}\right\}^{1/2}$$

where

a = $|l_s - l_e|$

c = $|L_e - L_s|$

s = 0.5 (a+c+γ)

L_s = Latitude of the satellite (normally equal to zero.)

and

Az = 180 + α when sub-satellite point is southwest of earth station

Az = 180 - α when sub-satellite point is southeast of earth station

CHAPTER 5

Conclusion

5.1 CONCLUSION

The E_b/N_0 values obtained over the entire Indian subcontinent do not vary appreciably. The E_b/N_0 values for satellite 2DT and INSAT-2E differ only marginally over the entire Indian mainland with values obtained for INSAT-2E being slightly higher The values obtained in the western part of India are nearly same but the values in the eastern part of India degrade by 0.22 dB. This is due to the fact that 2DT is located at 55 1^0 E and INSAT-2E at 83 ^{0} E and path loss for the eastern part is slightly more.

The link budget calculations have been done under severe power constraints. E_b/N_0 values obtained for various data rates in simulcasting for higher data rates of 3 – 5 Mbps are on the lower side and do not carry enough margin for maintaining the specified BER of 10^{-10}. This is mainly due to the power restrictions imposed on the digital carrier. Doordarshan, India is able to achieve good quality digital video broadcasting, even under severe power restrictions, by compensating it by using large size dish antenna (6.2 – 7.2 m) for reception which provide the receiving station with a G/T of the order of 25 dB/K. If reception is still to be done using a typical VSAT terminal with small dish antenna size then one or more of the following has to be adopted in system design considerations :

- Increase the digital EIRP, which may be possible for the case of INSAT-2E where more power can be allocated to digital carrier without deteriorating the analog signal. We can see in table 4.5 given in chapter 4 that the values of E_b/N_0 obtained for digital carrier increased from 6.82 dB to 10.40 dB when the EIRP was increased from 26 dBW to 30 dBW. This can also be done to improve the BER for the same data rate and bandwidth case.
- Use of receiving systems with lower system noise temperature to give a higher overall G/T.

- A compromise be made with lower data transmission rates.

In case of FDMA systems, the E_b/N_0 values obtained are less than 3 dB for the case of 5 carriers with data rates of 5-6 Mbps required for quality digital video broadcasting but improve to nearly 5.5. – 6 dB for large dish antenna reception.

5.2 SCOPE OF FUTURE WORK

The link budget calculations relevant for the Indian subcontinent can be further exacted by obtaining and considering specific satellite channel characteristics. An exhaustive analysis may be done to evaluate signal distortion on passing through input and output filters, input and output multiplexers and high power amplifier (TWTA or SSPA).

The non-linearities in the high power amplifier distort the bandlimited PSK signal heavily. Scope of modulation techniques like OQPSK and MSK [13]which avoid 180^0 phase transitions can be studied for application in satellite channels. Use of modulation techniques like Orthogonal Frequency Division Multiplexing (OFDM) and together with channel coding known as (COFDM) already popular in DVB-Terrestrial may also be studied [16].

Adoption of various channel-coding schemes that provide optimum coding gains can also be seen. In the case to concatenated RS convolutional Viterbi code, the effect of coding by changing RS (n,k) and convolutional code (r , constraint length) parameters can be studied. Use of Trellis Code modulation may be studied that can provide optimal bandwidth and higher coding gains

REFERENCES

1. WILBUR L. PRITCHARD and JOSEPH A. SCIULLI, "Satellite Communication Systems Engineering", Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1986.

2. TIMOTHY PRATT & CHARLES W. BOSTIAN, "Satellite Communications", John Wiley and Sons, Inc., 1986

3 ROGER L. FREEMAN, "Radio System Design for Tele Communications (1-100 GHz)", John Wiley and Sons, 1987.

4. SEBASTIANO TIRRO, "Satellite Communication Systems Design", Plenum Press, New York, 2nd edition – March 1994.

5. SIMON HAYKIN, "Communication Systems", John Wiley and Sons, 1995.

6. BRUCE R. ELBERT, "The Satellite Communication Applications Handbook", Artech House, Boston, London, 1997.

7. KAMILO FEHER, "Digital Communications, Satellite/Earth Station Engineering", Prentice Hall, Inc., Englewood, Cliffs, New Jersey, 1983.

8 JONATHON Y.C. CHEAH, "Practical Wireless Data Modem Design".

9. G.M. DRURY, "DVB Channel Coding Standards for Broadcasting Compressed Video Services", Electronics and Communication Engineering Journal, February 1997.

10 J. SESENA, " The DVB Satellite Cable and SMATV Systems, why the technical choices were made", EBU Technical review, Winter 1995.

11. AMITABH ROY, G. MAHEEDAR, S.K. BOSE, "A Linux Based Asymmetric IP Router for Hybrid Networks", Technical report, TR-01/1999.

12. INSAT-2C and 2D spacecraft Communication Payload Functional Specifications, Department of Space, Bangalore, May 1994.

13. SUBBARAYAN PASUPATHY, "Minimum Shift Keying: A Spectrally Efficient Modulation", IEEE Communications Magazine, July 1979.

14. NSENSE E. Muntanga, "Technical Memorandum of Lease Transmission Plan Program", INTELSAT Organization.

15. G M DRURY, "Broadcasting By Satellites", International Journal of Satellite Communication", Vol. 12, 395-417(1994).

16. PAUL DAMBACHER, "Digital Television Broadcasting and Operation", Springer – Verlag, Berlin Heidelberg, 1998.

17. MICHAEL ORZESSEK & PETER SOMMER, "ATM & MPEG-2 Integrating video into broadband networks", Prentice Hall PTR, Upper Saddle river, NJ 07458, 1998

18. ROBERT M. GAGLIARDI, "Satellite Communications", CBS Publishers & Distributors, Delhi 1987.